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POSSIBLE APPLICATION OF ELECTRONIC DEVICES TO FOREST FIRE DETECTION

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This paper reports and describes the present status of research on electronic fire detection systems at the Northern Forest Fire Laboratory. It outlines the problem areas where electronic systems may prove valuable in solving detection problems; it also describes several systems under consideration. Rigorous analysis of each problem discussed is beyond the scope of this paper. For those interested in pursuing this subject further, a list of references is included.

INTRODUCTION

The efficiency of any forest fire detection system depends on its ability to cover the maximum possible areas where fires might start, to detect fires while they are small, and to relay the information on fire size and probable behavior to fire suppression groups. The major objective of fire detection research is to develop a system that will detect the largest number of fires in the shortest possible time.

The highly varied nature of forested areas complicates the fire detection problem. Many forested areas, particularly those under private or state ownership, are in regions of high population density where the commercial and recreational activities contribute to the incidence of forest fires. Other vast areas of the national forests are wilderness or primitive areas devoid of roads or normal communication systems. Here the major problem is caused by nature--the lightning storm. In Alaska, for example, millions of acres with valuable vegetative cover are virtually without detection coverage.

In present day forest fire detection systems, a combination of fixed lookout stations and aircraft patrols has been used with moderate success. Studies of this system have shown that lookout observers are more successful than aircraft patrols in detecting fires that smoke up quickly after origin.

Nearly 60 percent of the fires were detected by lookout observers within 4 hours as compared to only 23 percent detected within this time by aircraft patrols. One reason for this difference is that aircraft patrols are often delayed until that period of the day when smoke can be most readily seen from the air (1).[1]

What are the major physical problems in fire detection?

1. Detection at night.--Lightning fires start at all hours, but peak occurrence is between 4:00 and 6:00 p.m. Most man-caused fires are detected between 2:00 and 4:00 p.m., the peak burning period of the day. Obviously, many of these fires have lain dormant until afternoon burning conditions are conducive to fire growth and spread. Thus, the crucial hours in fire detection are from midafternoon until late evening. Several factors combine during these hours to hamper present detection techniques. At dusk, when the detection effort should be at its greatest, the light aircraft used in aerial detection must give up for the night and await dawn to renew the search. For efficient visual detection these aircraft must fly at very low levels. Low-level night flying in mountainous terrain is too hazardous.

2. Detection through smoke and haze.--Another inhibiting factor is the natural behavior of the atmosphere. At the end of the daily solar heating cycle, temperature inversions form in the valleys, concentrate smoke and haze in the lower levels, and seriously reduce visibility. To make matters worse the smoke and haze usually persist until midmorning of the next day to further hamper the early morning detection patrols. A detection system that could "see" through smoke and haze and that could operate during hours of darkness should markedly improve detection efficiency.

3. Detection of widely scattered fires.--Widely scattered lightning storms present a particularly difficult detection problem. They often start at night, but search must be delayed until the daylight hours. Wide areas must be searched because exact locations of the storms are not known. As a result, probability of detection is low and costs are very high. A system that could track moving storms and localize the areas receiving lightning strikes should increase detection efficiency following lightning storms.

The major research effort on detection is directed toward overcoming deficiencies of present systems by applying advances in electronic systems to the problem. Radar and radio direction-finding techniques are being applied to the problem of tracking thunderstorms and localizing the areas of lightning strikes. Infrared devices, with the ability to "see" heat sources over great distances through smoke and haze may be used to detect fires. Television may have some application in surveillance of areas of extreme fire danger. Let us next examine each of these possibilities in detail.

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[1] Underlined numerals in parentheses refer to numbered items in the References section.

JAMES C. SPACE

INFRARED

Before proceeding with a discussion of infrared devices, it may be pertinent to define the term "infrared" and briefly describe some of its properties. Gamma rays, x-rays, ultraviolet, visible light, infrared, microwaves, and radio waves are all terms arbitrarily assigned to specific wavelength regions of the entire electromagnetic radiation spectrum. Visible light is defined as that portion of the spectrum from 0.4 micron[2] to 0.7 micron (2). Infrared is defined as that portion of the spectrum from 0.7 micron to 1,000 microns. Any body whose temperature is above absolute zero radiates electromagnetic energy. At any specific temperature most of this energy is radiated over a relatively narrow band of wavelengths. The wavelength at which maximum energy is radiated is inversely proportional to the absolute temperature of the body (3). A body at 80° F. radiates its maximum energy at 10 microns, but one at 800° F. at 4.3 microns. The amount of radiant energy that penetrates any substance is a very complex function of the wavelength of the radiation and the size of the particles in the substance (4, 5).

During the past several years forest protection personnel have been greatly interested in the possible use of infrared devices to detect forest fires. Several schemes have been proposed for either replacing or supplementing existing lookouts by infrared devices. To be effective, an infrared detector must have an unobstructed view of the heat source. In mountainous terrain the unobstructed view from a fixed ground point is called the "seen area." Therefore, an infrared detector installed at a lookout would provide surveillance of only the "seen area." Present visual lookouts provide surveillance of greater than the "seen area" by observing the smoke column from a fire. It has been proposed that an infrared detector could detect smoke columns by sensing the radiant energy from these columns. Within the limits of present technology such a scheme is not feasible. A convective column contains much heat energy, but the emission efficiency of these columns does not permit radiation of enough of this energy to be reliably detected by any infrared system now available.

"Seen area" may be increased by increasing the height of the observation point. This can best be accomplished by placing the observer in an aircraft flying at relatively high altitudes. An infrared detector installed in a high-flying aircraft could get a direct view of a fire with a minimum number of trees and hills obscuring its view. Attempts to apply infrared aerial photographic techniques to this problem have met with very poor results since infrared film is sensitive to only a very limited portion of the infrared spectrum--from 0.4 micron to 1.5 microns (3). Energy in the photographable portion of the infrared spectrum is produced only by very high temperature sources and is absorbed and dispersed very rapidly by smoke particles. Infrared film is slightly more effective in penetrating smoke and haze than is normal photographic film, but its spectral sensitivity is too limited to be useful in forest fire detection. To gain the advantages inherent to infrared scanning systems, we must use devices that are sensitive to energy in the region beyond 3 microns.

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[2] One micron is equal to 0.000001 meter.

Developments during the past 5 years in infrared detectors that produce an electrical signal proportional to radiant energy have permitted the design of infrared aerial mapping systems sensitive to a much larger portion of the infrared spectrum (1 to 10 microns). These devices permit observations of low-temperature heat sources through some types of smoke cover. The amount of infrared energy required to penetrate a smoke or haze cover is determined by the relation between the wavelength of the radiated energy and the size of the particles in the smoke or haze. Due to the complexity of calculating the amount of radiant energy that will penetrate a smoke column, it is not possible with the information currently available to determine accurately the effectiveness of infrared scanners in seeing heat sources through the varying smoke densities associated with forest fires (6).

The Northern Forest Fire Laboratory has studied infrared systems used in military activities and is experimenting with application of these systems to fire problems. During the 1962 fire season we plan to evaluate a Signal Corps infrared mapper on actual field problems to determine the limits of this system in the following applications: (1) detecting small fires through various conditions of smoke and forest canopies; (2) determining the perimeter and location of hot spots on project fires where normal visual observation is limited by smoke blankets; and (3) determining rate-of-spread of forest fires.

Aerial patrols for visual fire detection are best performed during conditions of bright sunlight at low sun angles so that smokes can be most easily seen. These conditions occur during the late afternoon. Since infrared systems do not rely on the sun's illumination, their use is not limited to daylight hours. One problem associated with night aerial patrols by visual means is accurately determining the location of a fire when normal ground reference points cannot be seen. Infrared mappers provide good resolution of such landmarks as lakes, streams, and roads and thereby offer a means of determining the true location of a fire. This approach may well provide detection of fires during the nighttime and thus allow suppression forces to attack earlier than is now possible.

RADAR

A radar set operates by transmitting pulses of microwave energy in a narrow beam and detecting the energy reflected by a target. By measuring the time elapsed between the transmitted pulse and the received pulse, it determines the distance to the target. By knowing the direction in which the pulse is transmitted, the operator can get a fix on the target. The range at which a target can be detected is determined by the amount of power transmitted, the reflecting properties of the target, and the sensitivity of the receiver. Microwave energy, like light, travels in straight lines. To be effective at long ranges a radar must be installed on a high point in the terrain.

Radar equipment provides data on both size and location of large accumulations of atmospheric moisture normally associated with cumulonimbus cloud formations. Because of this capability, radar is useful in detecting the buildup and tracking the movement of cloud systems that may produce lightning.

The Northern Forest Fire Laboratory is now studying radar as a possible tool for detecting and evaluating lightning-storm situations. Project Skyfire has used radar to gather data on lightning-storm characteristics. More recently, the U.S. Weather Bureau has installed a WSR-57 radar on Point 6 Mountain, an 8,000-foot peak 9 miles from the Laboratory. This powerful weather radar, aided by a microwave relay system, is transmitting data to both the fire-weather offices and the Northern Forest Fire Laboratory; it should prove a valuable facility in evaluating and predicting lightning-storm situations.

During the 1961 fire season a pioneer experiment in use of radar applications as an aid in fire detection was conducted on the Deerlodge National Forest near Philipsburg, Montana. At the Black Pine fire lookout station, a modified Navy type SO-12 radar was installed.

Results of the Deerlodge experiment showed that:

a. Radars of the SO-12 type can be installed and operated at remote field locations without undue difficulty.

b. The effective and dependable range of this type radar in detecting precipitation cells is about 70 nautical miles.

c. The radar can effectively detect, locate, and track precipitation cells, but some other equipment is needed to determine whether these cells are producing lightning.

Research to date in radar uses has demonstrated that its main value for assistance in fire detection is in obtaining data on general storm situations and the broad areas of possible lightning activity. Ligda and others have shown that radar can detect actual lightning discharges under some situations

(7), but these techniques are not practical for operational use in fire detection. Radar is principally a strategic tool. It can aid in fire-detecting planning and management by providing data on the nature and movement of storms and information for weather forecasting.

SFERICS

Sferics (a contraction of the term "atmospheric electricity") is a term used to designate radio direction-finding schemes employed for detecting and tracking lightning storms (8). Lightning strokes radiate large amounts of electromagnetic energy in the long wavelength portions of the radiowave spectrum (9). Energy at this wavelength travels not only in straight lines, but also along the surface of the earth. Hence, sferics receivers can detect lightning strokes at distances of several thousand miles and do not require mountaintop locations.

The present state of development of sferics equipment permits measurements of bearing to the discharge but does not permit ranging from a single station. Careful analysis of sferic wave forms sometimes enables determination of approximate distance to the discharge and differentiation between cloud-to-cloud and cloud-to-ground discharges (10, 11). Usually, this is possible only on discharges from storms more than 100 miles distant. It does not appear feasible, with the presently available technology, to build a computer to perform this analysis automatically. Single-station sferics lightning tracking is therefore not presently possible. A combination of radar and sferics is usable, but the range of such a system is limited to the range of the radar employed. If two or more sferics stations are used, fixes can be obtained by triangulation. Sferics receivers are inherently much less expensive than radar, and since they do not require mountaintop locations their installation and logistic costs are much less. It appears that a lightning tracking system composed of two or more sferics receivers is a much more desirable system than a radar system or a radar-sferics combination. If additional weather information is desired, then the radar-sferics combination is the more desirable.

Sferics equipment used by the Air Force Severe Storm Warning Center and the Bureau of Standards is not directly applicable to forest fire agency use. It will be necessary to develop some new circuitry to provide data in a form that is directly applicable to the forest fire problem.

TELEVISION

Television cameras are sensitive to only that portion of the electromagnetic spectrum called visible light. A television camera can see nothing that cannot be seen by the human eye; in fact, it is much less sensitive than the human eye. A television camera, therefore, cannot detect as well as a human observer. Television may have some application in areas where it is undesirable to maintain a manned lookout, but any decision to use television must be based on comparison of the costs involved with the advantages to be gained. Problems associated with television installations are well defined in current engineering practices.

FUTURE DEVELOPMENTS

All the electronic systems discussed above have certain useful applications to fire detection problems. The extent to which electronic devices and techniques may be used in fire detection depends upon results of research now under way or planned. The planned program includes:

Infrared.--Experiments will be conducted with an infrared serial mapper mounted in a patrol aircraft to determine the feasibility of:

1. Detecting and locating fires with this equipment.

2. Measuring perimeter and location of "hot spots" on project fires.

3. Measuring rate-of-spread of project fires.

Radar.--Project Skyfire research of lightning-storm characteristics, in which radar is one tool, will aim at gaining better understanding of the specific nature of fire-setting lightning storms. From this knowledge, techniques can be developed for early storm warnings and evaluations of wet or dry storms, fast- or slow-moving storms, and severe or moderate storms.

Sferics.--Special equipment will be developed to test the possibilities of locating specific lightning discharge areas. Techniques will be developed for mapping these areas and for dispatching patrol aircraft to them to detect fires.

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